BROOKS

The Design of a Rotary Engine

Electrical Engineering

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1917

THE DESIGN

OF A

ROTARY ENGINE

BY

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THESIS

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IN

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THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

Frederick Augustus Brooks,

ENTITLED The Design of a Rotary Engine.

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE

DEGREE OF Bachelor of Science in Electrical Engineering.

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HEAD OF DEPARTMENT OF Electrical Engineering

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CHAPTER I

INTRODUCTION.

1. STATE OF THE ART. Numerous attempts have been made to produce a rotary engine with little success hitherto. In any book on Kinemetics of Machinery several arrangements are shown, each workable but not developed into a practical machine. Of all these types the only one on the market today is the Augustine Rotary Steam Engine.

(a) Principles of the Augustine Rotary Engine. The Augustine machine consists of a cylindrical casing (A) in which is mounted a cylinder (B) so placed as to rotate in contact with the bottom of cylinder (A). In (B) two slots are cut diametrically opposed and in these slots plates operate so as to continually maintain contact with cylinder (A). As the cylinder (B) rotates these plates form closed chambers of varying volume and hence steam admitted as shown will expand forcing (B) to rotate in the direction indicated. It will be noticed that only line contacts are available on the surface of (A) and hence there must be constant wear and leaky operation. In spite of this the Augustine engine operates successfully and is quite convenient for many installations on account of its inherently small size.

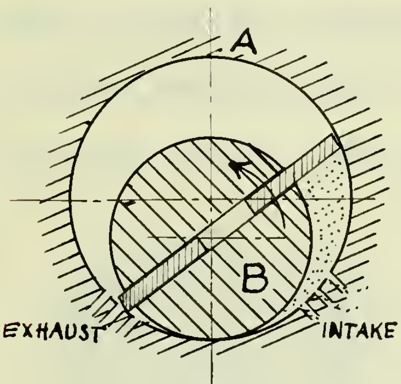

fig. 1.

(b) Present Positive Rotary Blowers. There are several positive rotary blowers now in use, some being different adeptations of the general construction of the Augustine engine, but the best

known type is the impeller pump. In this case there is continual contact at or near (A) and along the surfaces (B) and (C). As the two dumb-bell shaped impellers rotate in opposite directions a volume (D) is trapped between the two ends of an impeller and the cylindrical surface, and is carried from the intake side to the exhaust.

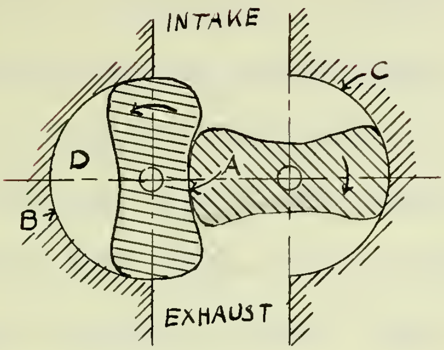

fig. 2.

Here it is prevented from being returned by the other impeller which maintains constant contact at (A). This type also depends on line contacts and is useless as a prime-mover.

(c) Gear Pumps. Gear pumps act on really the same principles as the impeller pump, there a number of teeth instead of only two. This pump will also operate if one of the gears is replaced by a worm gear. The pump is inapplicable for engines on account of the small opportunity for expansion.

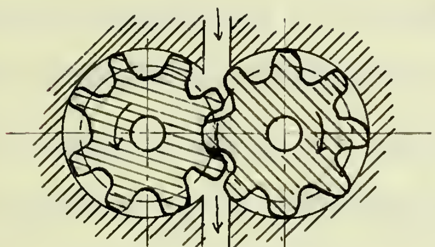
fig. 2a.

2. IMPORTANCE OF ROTARY MACHINES. Rotary machines are important for their longevity, absence of vibration and possible lightness.

(a) Longevity. The failure of present machines is due primarily to fatigue of parts subject to strains of reciprocating masses. This is shown by the fact that airplane motors at present usually will last only 100 hours of service.

(b) Absence of Vibration. The vibrations of some reciprocating engines can be neutralized externally by proper space and time

relation of parts, but internally the tendency exists and ultimately will cause the engine to fail. A rotary engine can be built inherently balanced in every part and the only strains will be due to the centrifugal and power forces.

(c) Possible Lightness. In rotary machines the crank is integral with the equivalent piston and hence all conecting mechanisms are done away with. This makes a rotary machine inherently lighter and far more compact than a reciprocating engine of the same strength and materials.

3. DEVELOPMENT OF THIS ROTARY MACHINE. The rotary described in this thesis was developed step by step, not by derivation from other rotary machines, but in accordance with the fundamentals of mechanics and gas engine design theory. The complete machine is strictly an adaptation of the cycle of the present reciprocating internal combustion engine to a true rotary engine.

(a) Applicability of the Grooved Rotor. The machine depends upon a grooved rotor mounted in a close fitting cylindrical casing. The annular grooves are stopped off at chosen places by lugs set therein, thus forming closed annular sections or compartments.

(b) Positive Action with Rotary Valves. Rotary disks mounted in the casing project into these compartments deviding them into chambers of variable volume as the rotor revolves. The lugs pass the disks thru the cavities cut out for them in these rotating disks or valves. The lug approaching the rotary valve is equivalent to a piston toward the cylinder head. When the lug passes thru the valve it is as if the cylinder head opened, allowing the piston to pass thru; and closed after it. Then as the lug moves away it

is equivalent to the piston receding. Hence, the operation is positive like that of the ordinary piston in a cylinder.

(c) Servicability Wherever Pistons are Used. The similarity makes this rotary construction applicable to every case in which pistons and cylinders are now used . Furthermore, the valve action for pumps and motors is greatly simplified. The advantages of a rotary machine over a reciprocating machine are well recognized by engineers.

CHAPTER II

MECHANICAL CONSTRUCTION OF UNIT.

Every engine is composed of one or more units of fundamental parts, consisting of the cylinder,piston, connecting rod, and crank in a gas or steam engine, or of separate stages in a steam turbine; and the functions, motions, and forces occuring in the several units combine in the polyunit machine to produce the desired flow of power. When an engine must conform to certain requirements it is desirable to have each unit separately exhibit these requirements.

1.REQUIREMENTS. By definition a true rotary engine must have:

(a) Unidirectional Motion. The prime object of a rotary machine is to obviate strains and mechanical drag caused by the overcoming of the inertia of reciprocating masses.

(b) Circular Motion. Any non-circular motion is equivalent to some combination of circular motions of different speeds or of circular and reciprocal motion, as may be shown by resolving into primary components any complex motion.

(c) Continuous Rotation. This is necessary to keep the inertia of the rotating parts from producing effects similar to those caused by reciprocating masses. However, if the rotating motion is continuous, but not uniform, this same effect will act as a flywheel and be quite advantageous in making the rotation constant.

(d) Positive Action. The machine under consideration is a rotary adaptation of the cycle of a reciprocating gas engine. If not positive, the engine would be closely analogous to some type of turbine based on another distinct theory.

2.DEVELOPMENT. To develop the theory of action and the construction

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of one engine unit in accordance with the rotary engine requirements just presented, the action of the molecular pump will be described first. It consists of a grooved cylinder rotating about its axis at a high speed, mounted in a close fitting cylindrical casing from which, at one point, a block extends down into the groove separating the intake and exhaust ports. This machine

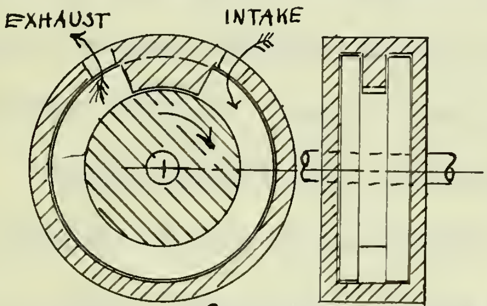

fig. 3.

conforms to the first three requirements; but its action is not positive i.e., there is a free passage from exhaust to intake ports which is overcome merely by the extreme rotating speed exceeding the molecular velocity of the gas.

If a lug (A) were fixed in the rotor there would no longer be a free path between ports, but if this machine is to rotate there

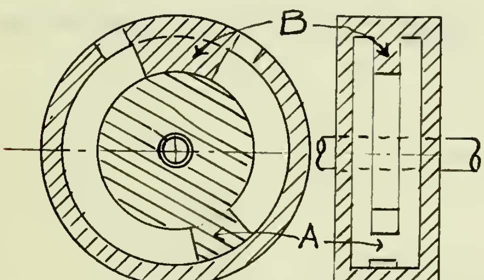

fig. 4.

must be some means of allowing the lug (A) to pass thru the block (B) without destroying the function of (B). This can be accomplished by making (B) movable radially, and synchronizing its removal and replacement with the passage of (A) past that point. This, however, brings in the objectionable feature of a reciprocating part, so to obviate this a rotating disk making rolling contact with the bottom of the groove is

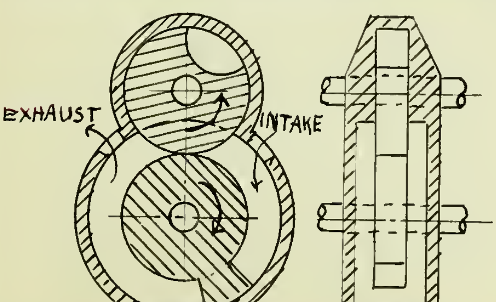

fig. 5.

substituted for block (B). In this disk a cavity is cut of just sufficient size to let the lug (A) pass thru as both rotate. Now this forms a positive rotary element conform-

ing in a rough way to all the requirements. As will be shown later, it is important to make the cavity in the disk or rotary valve as small as possible, likewise to make the block (A) of the maximum volume which can pass thru the rotary valve. This requires the determination of the paths of the conflicting edges. The best shapes are those in which the corners of the lug scrape the entire surface of the valve cavity, and the corners of the cavity follow closely the contour of the lug.

These curves are determined graphically. Securing a rolling contact of the rotary valve on the bottom of the groove by choosing equal radii and velocities, the angular displacement of one will be equal but in the opposite direction to the displacement of the other. On this basis the path of any point on one can be determined with relation to the other by the following method, as shown on the next page.

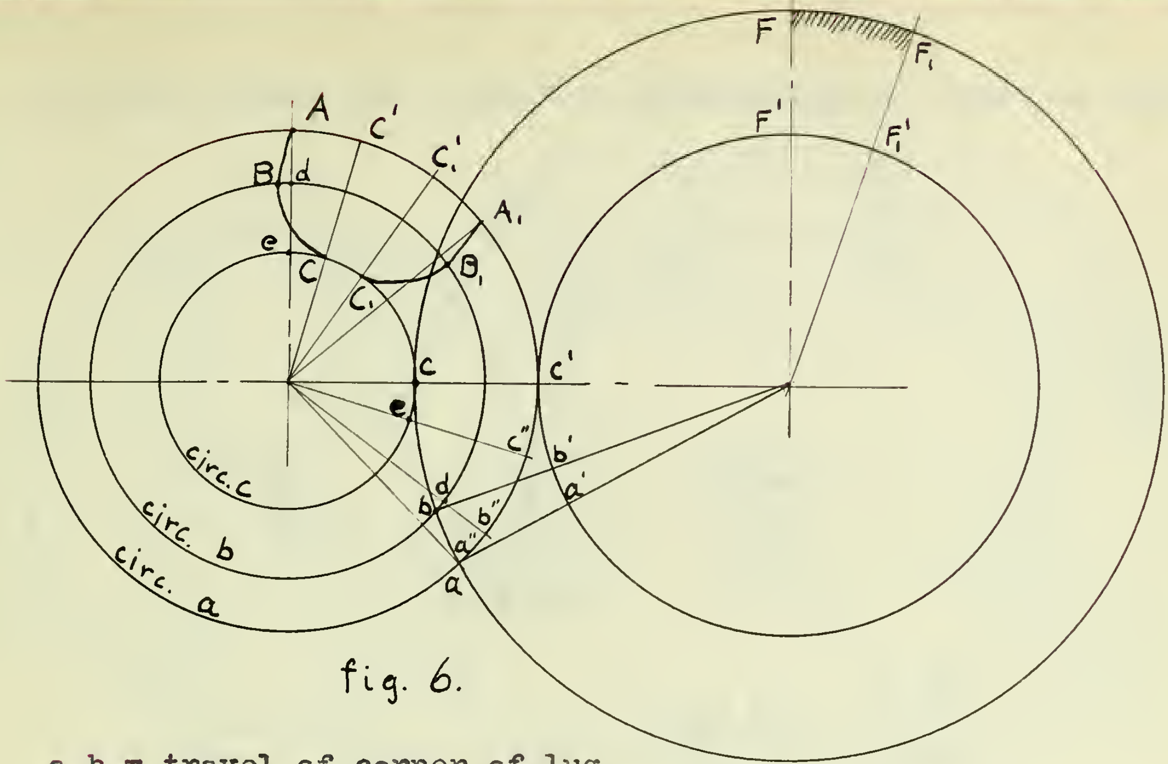

fig. 6.

a b = travel of corner of lug.

a"b"= angular displacement laid off = a'b'.

∴ b d = distance of point b on circ. b from center line of starting point on the periphery.

a c = travel of point.

a"c"= angular displacement laid off = a'c'

∴ c e = distance on circ. c of point c from center line of starting point on the periphery.

By taking a large number of points and replotting with coincident center lines there is produced the desired curve A B C. This definitely fixes the shape of the cavity, since it must be symmetrical, the angular separation $C'C_1'$ being equal to $F'F_1'$ the angular length of the top of the lug.

The same method can be used in determining the shape of the lug.

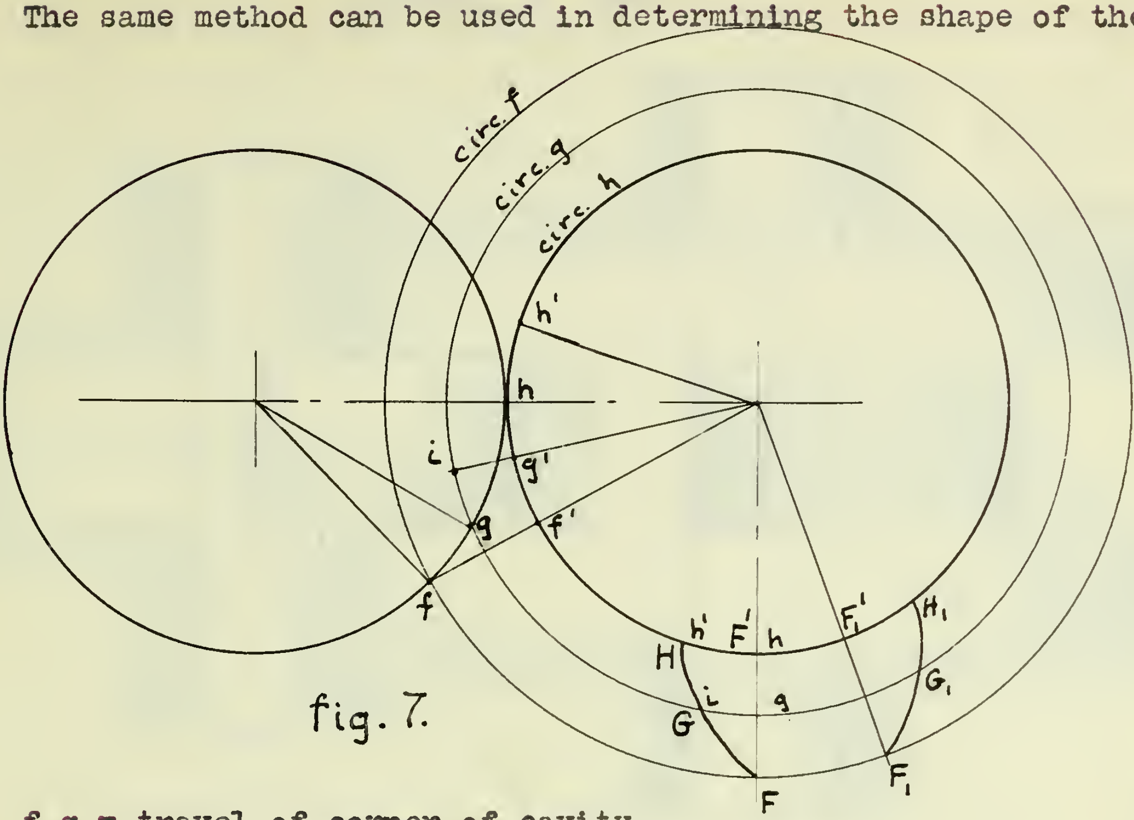

fig. 7.

f g = travel of corner of cavity.

f'g'= angular travel of rotor = f g.

∴ g i = distance of point g on circ. g from center line of f.

f h = travel of corner of cavity.

f'h'= angular travel of rotor = f h.

∴ h'h= distance of point h on circ.h from center line of f.

Taking a large number of points, the curve can be determined very accurately and the lug constructed with symmetrical curves for opposite sides, which are separated angularly by the distance $F'F'_1$ equal to $F'F'_1$ of fig.6.

3. RESULT. Applying these curves and using appropriate dimensions the accompanying drawings, plate A, show a unit adapted to rotary engines. The sides of the grooves can be made thick, as shown, and equipped with equivalent piston rings if desired. Gear

DRAWING OF UNIT

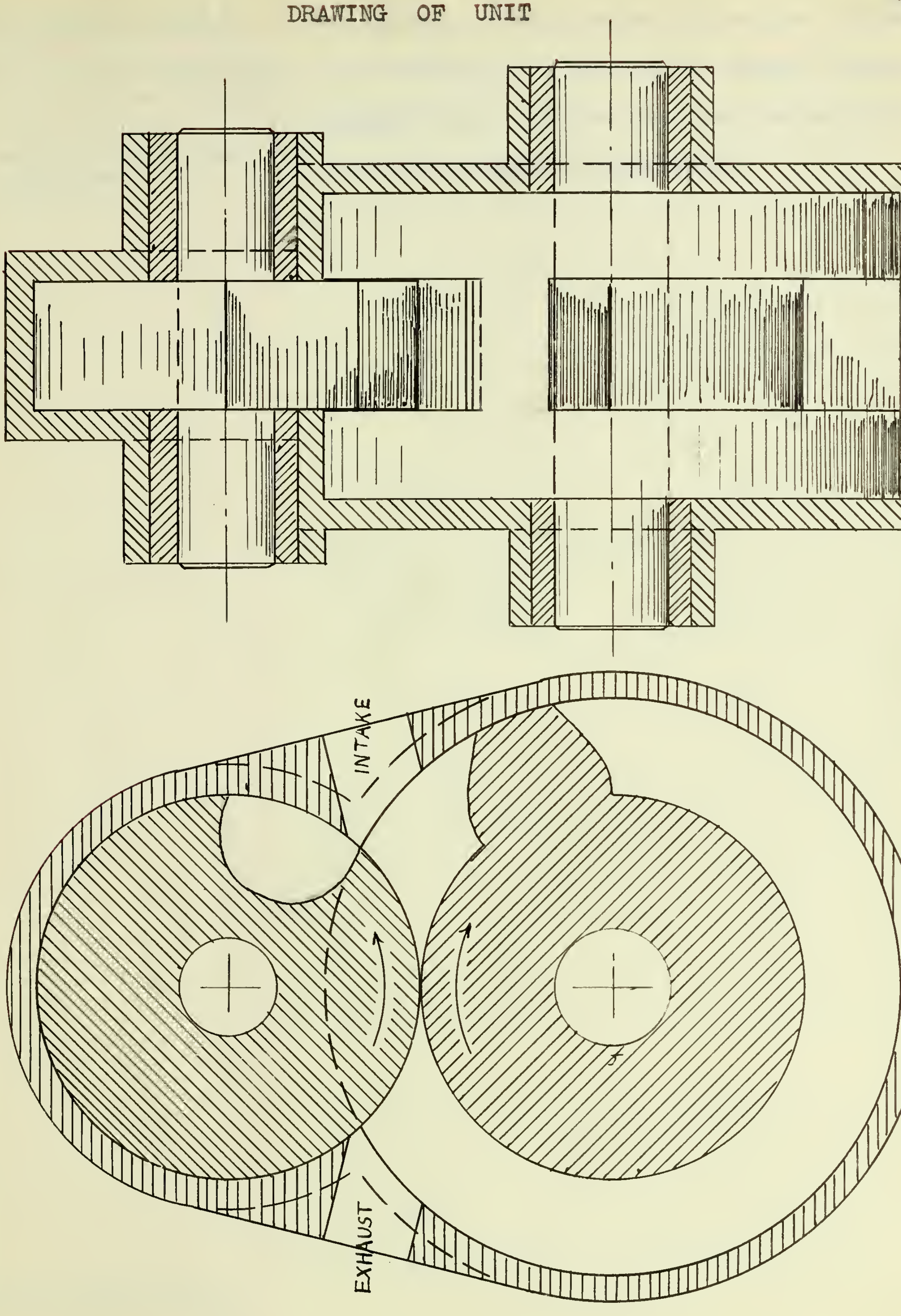

PLATE A.

n the bottom of the groove and on the rotary t will operate as a spur gear, except during s passing thru, the two rotating parts being s time and otherwise controlled.

teeth can be cut in the bottom of the groove and on the rotary valve when the unit will operate as a spur gear, except during the time the lug is passing thru, the two rotating parts being out of mesh at this time and otherwise controlled.

CHAPTER III

OPERATION OF UNIT.

1. CRITICAL POINTS OF LIMITING VOLUME. It is impractical to depend on the accuracy of the fit of the lug in the valve cavity to hold gas pressure, since at best there are only two line contacts, see fig.9, which quickly wear away. Hence a compressed gas cannot be maintained after the rotary valve comes out of mesh with the bottom of the groove, see fig.8. This is the first critical point, the volume here being the effective minimum.

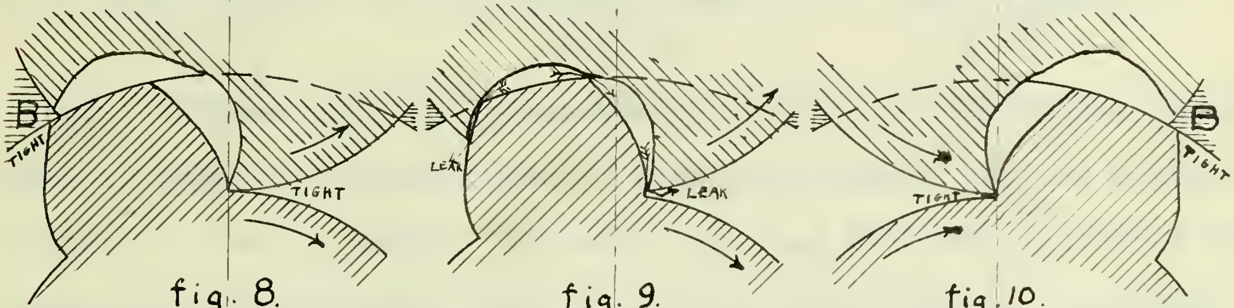

fig. 8. fig. 9. fig. 10.

In this position it is evident that to make the construction effectively hold pressure the surface of the lug must extend far enough to overlap the casing edge at B. Fig.10 shows the second critical point. The volume of the cavity which is not occupied by the lug is again the limiting volume of this construction. This is the smallest volume obtainable that will maintain gas pressure.

As will be seen, it is quite desirable to make this limiting volume as small as possible and, since the volume of the cavity varies with the angular length of the lug, this should be made a minimum and yet furnish satisfactory surface contact at B.

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2. INTAKE.

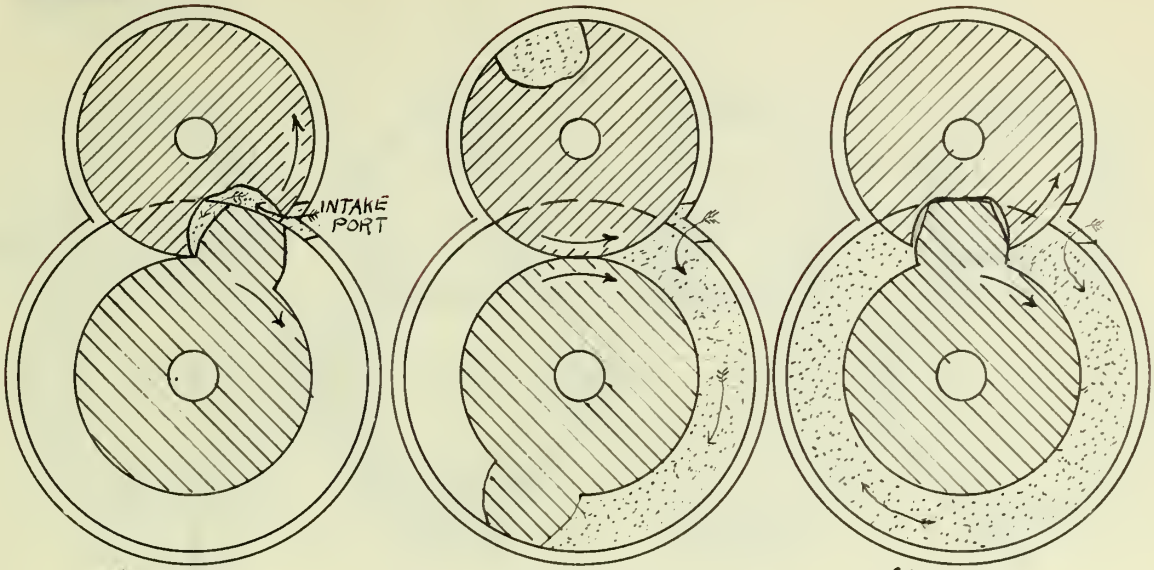

fig. 11. fig. 12. fig. 13.

Fig. 11 shows the first position of the unit at which the intake port is open at the condition of limiting volume. As the machine rotates in the direction indicated, the lug will move out from the cavity and advance away from the rotary valve causing the annular chamber behind it to increase. This action of increasing volume creates a suction which draws in the gas charge as shown in fig. 12, and finally fills the entire annular groove when in the position of fig. 13.

3. COMPRESSION.

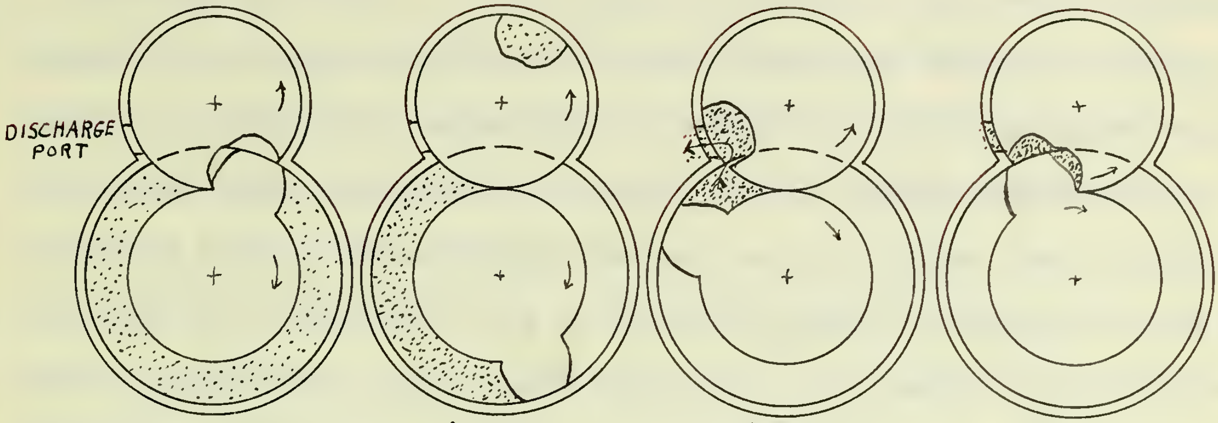

fig. 14. fig. 15. fig. 16 fig. 17.

Fig. 14 shows the start of compression, the whole annular groove filled with the charge. In fig. 15 the charge is half compressed. Fig. 16 shows the discharge port open and the charge compressed to about four atmospheres. In fig. 17 the compression is a maximum at the moment of limiting volume and the discharge port just closed.

4. EXHAUST AND EXPANSION. Exhaust and expansion, being reverse processes of intake and compression, can be accomplished by a reversal of function without reversal of rotation. The intake series of drawings taken in backward succession, figs. 13, 12 and 11, show this reversal of function, illustrating exhaust, and in like manner, figs. 17, 16, 15 and 14 describe expansion.

CHAPTER IV

COMBINATION OF UNITS.

1. DIVISION OF CYCLE. In a regular four-cycle internal combustion engine the complete cycle is divided into four working strokes; intake, compression, expansion and exhaust. Each of these operations has been described as applied to the rotary construction. Although exhaust is normally the reverse of intake, and expansion opposite to compression, it is most advisable to separate both of those symmetrical operations, since in a gas engine the ignition occurs between the compression and the expansion, and in order to operate economically the hot gases must be kept separate from the fresh charge. This is secured by using the lug in one groove to produce the compression ahead of it and the intake behind it at the same time. The only objection is the difficulty of obtaining the proper valve action to control both operations independently while they overlap each other between the two critical points as the lug passes thru the rotary valve.

Expansion and exhaust can likewise be performed together in one groove, the expansion taking place behind the advancing lug as the exhaust is accomplished ahead of it. In this case there is no conflict of valve actions, since the transfer of compressed gas into the expansion chamber is brief, and the exhaust port at the end of the annular chamber is open continuously.

2. RELATIVE POSITION. Engine units should be combined only in proper cyclic and mechanical relation.

(a) Cyclic relation. These two grooves mentioned above operating simultaneously should obviously be so set in relation to each

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other that, as the compressed charge is being delivered by the compression chamber, the expansion chamber in the adjacent groove is receiving a compressed charge at the same time. This arrangement permits a direct transfer of the charge from compression to expansion chambers, and does away with a pressure-chest into which the compressed gas would otherwise have to be delivered at one time and withdrawn at another.

(b) Mechanical Relations. One other consideration is of importance in connection with relative position, namely the question of gearing. It has been shown that gear teeth can be cut on the rotary valve and in the bottom of the groove to minimize the leakage at the point of rolling contact. But evidently this gearing is discontinuous between the two positions of limiting volume, and for smooth operation other gearing must be provided to at least fill that gap.

If two units are to be operated simultaneously one can be offset with respect to the other so that if both units are mounted on the shafts, one groove can be in mesh while the other is out, and thus maintain rotation. This varies very conveniently with the cycle relation since the transfer of the compressed gas cannot last beyond the position of limiting volume, or meshing, in the compression chamber, and it cannot begin before the point of limiting volume in the expansion chamber. Time must be allowed for transfer, hence these critical points of meshing necessarily overlap, so, in one or the other groove the rotary valves are constantly geared with the rotor.

3. COMPOUNDING. A further combination of units can be effected

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if it is desired to obtain compound expansion. Another unit may be added so that either the exhaust gases from the original expansion chamber can be further expanded in the new groove or, as arranged in this gas engine, the rate of expansion can be increased after rotating 180°. The latter arrangement consists of a port which opens after 180° rotation of the original expansion chamber, allowing the gas to be admitted also in the auxiliary groove at its limiting position, then the expansion will take place for the remaining 150° in two grooves instead of in one.

This uses only half of the auxiliary unit and hence it can be made double; that is, a complete unit in 180° instead of 360°, by adding diametrically another rotary valve and lug. With this construction the compound expansion can take place behind both of the lugs in the new groove and produce the effect of triple expansion. However, this compound expansion lasts only 150° since at that time the exhaust port in the original expansion chamber opens and, all the expansion chambers being connected, any remaining pressure is lost at this instant. In this way the extra double unit is in use only half the time.

By adding another primary expansion chamber at 180° to the first, the compound expansion of the new unit will fit exactly into the unused part of the compound chamber, then all three expansion chambers will be in full operation continuously.

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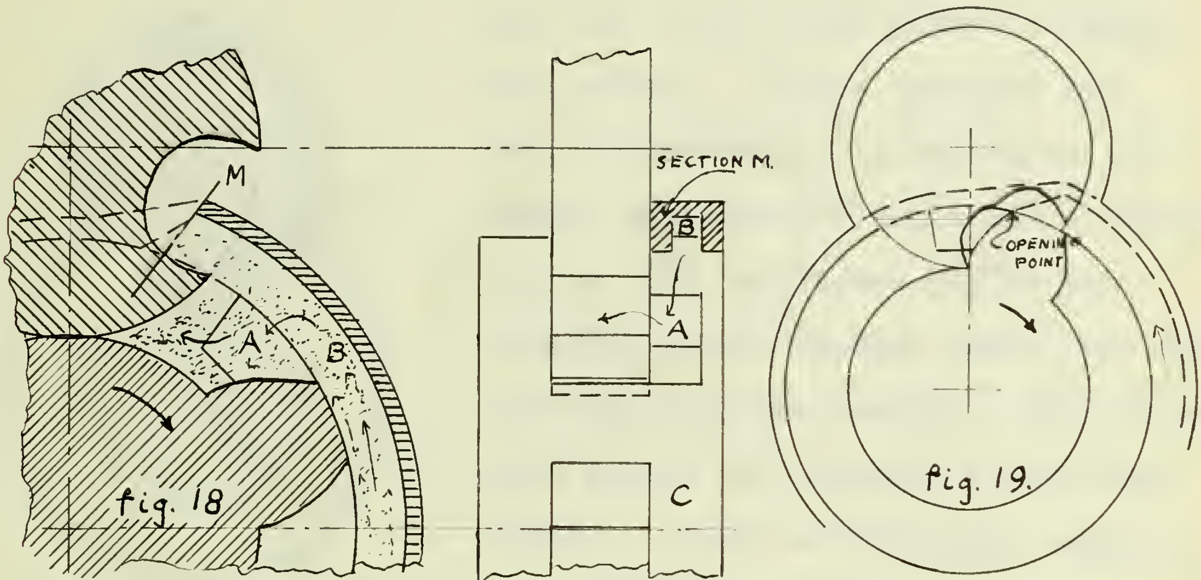
CHAPTER V

COMPLETED GAS ENGINE

1. INTAKE. Intake and compression occur in the same groove simultaneously behind and ahead of the lug and, as mentioned before, the valve actions for the two functions overlap and must be independent. This is accomplished by employing the annular partition between grooves as a disk-valve in conjunction with the casing.



In the casing opposite the center line of the circumference of the partition (C) a port (B) is constructed, open thruout its length to this circumference. To act in conjunction with this, a port (A) is cut immediately behind the lug, extending just beyond the center of the partition as shown in fig. 18.

Intake should begin at the second critical point illustrated in fig. 19; hence the forward edge of the port (A) must pass the back edge of port (B) at this moment. Then the operation will proceed for nearly one revolution with continued free passage for the incoming charge until the first critical point is reached

as the lug again enters the valve cavity. Connecting the intake manifold at the forward end of this intake port, the path of the incoming gases will decrease in length, contrary to reciprocating engine practice. With this arrangement the intake will close with nearly atmospheric pressure on account of decreased throttling.

2. COMPRESSION. Compression begins also as soon as the second critical point is passed as shown in fig.20. Then compression will progress as discussed in Chapter III to the first point of limiting volume. At this position the transfer valve is closed and as the corner of the valve comes out of mesh, fig.19, the compressed gas in the limiting volume expands ahead into the now closed intake chamber. This expansion raises the pressure of the new charge so that the following compression finishes with a greater pressure and the quantity passing thru the transfer port is increased slightly. But also the gas in the limiting volume is at a higher pressure and raises the starting pressure even more than before. This cumulative process will continue until the quantity of gas leaving at high pressure is equal to the quantity sucked into the intake chamber at low pressure.

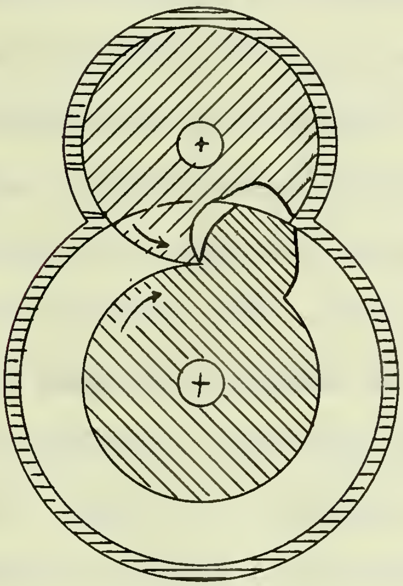


fig. 20.

3. TRANSFER OF COMPRESSED CHARGE. The transfer of the compressed charge to the expansion chamber in an adjacent groove should be

accomplished with increasing pressure in order to obtain maximum pressure at the time of ignition. It has been shown that the transfer valve cannot be open from the compression chamber after reaching the first critical point. Similarly the transfer cannot begin before the second critical point in the expansion groove. But at this opening position the limiting volume contains so little gas that any incoming compressed charge will lose some of its pressure. While the two chambers are in communication the rate of change of volume of one will balance that of the other and the first drop in pressure will not be regained. If the compression groove had a greater width than the expansion groove, then during the transfer more gas would be discharged from the compression chamber than taken into the expansion chamber, and the pressure would rise as the transfer proceeded. By extending the angular duration of the transfer, the pressure just previous to expansion into the limiting volume of the expansion chamber is kept below that obtained at the end of the transfer. The maximum pressure would then occur just previous to ignition.

Another advantage of extending the transfer is the reduction of the percentage of compressed charge lost in the limiting volume of the compression chamber. The expansion of the remaining gas into the closed intake chamber is an irreversible process and hence inefficient.

The construction of a larger compression and intake chamber would make the engine unsymmetrical so, instead, a double unit is used, the compression and intake of both sides acting in parallel. This delivers its double charge every 180°, which is timed cor-

rectly for two expansions per revolution.

4. EXPANSION. The expansion operation is described in chapter III part 4. This operation can be used for either simple or compound expansion.

(a) Single Expansion. These two charges delivered per revolution imply two primary expansions which occur alternately in separate grooves. These two units are adjacent, the partition between the grooves can be constructed to act as a rotary disk-valve admitting the charge first to one groove and then to the other. This necessitates piping the compressed charge to a port in the casing opposite the periphery of the common annular wall. Like (A) in fig. 18, two ports are cut on opposite sides, each port from the center of the partition to the back of a lug. A spark plug is placed in its casing a little beyond the transfer port so that as the rotor rotates, the port from one lug will first open to the compression transfer port and immediately thereafter to the spark. This permits ignition at maximum pressure just as the transfer port is closed, and furthermore pockets the spark plug so that it could be replaced by a hot-wire and the ignition occur only at the proper time. After ignition, expansion takes place as described in chapter III part 4.

(b) Compound Expansion. Compound expansion can be arranged as discussed in chapter IV part 3. With uniform sized grooves this compounding will permit a larger expansion than compression, which is desirable partly for increased efficiency but mostly for the balancing and gearing of the complete gas engine. The double unit intake at one end, and the double unit auxiliary at the other can be set in 90° relation for perfect balancing and

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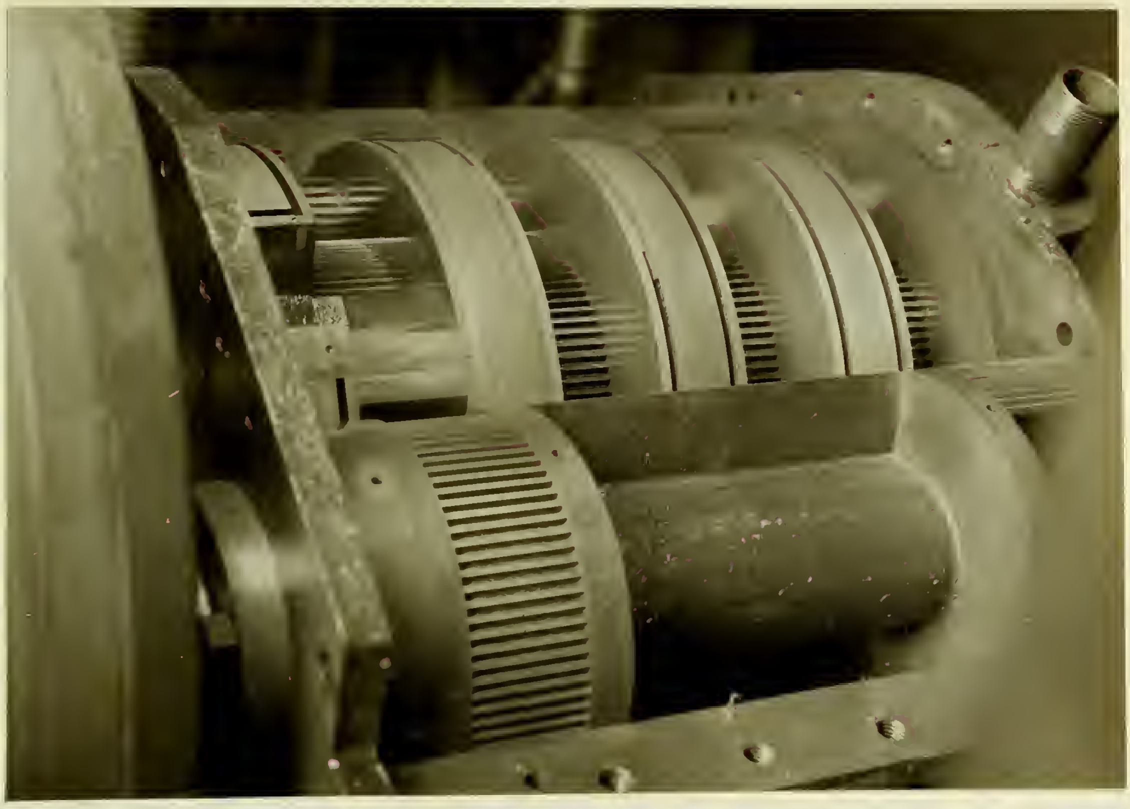
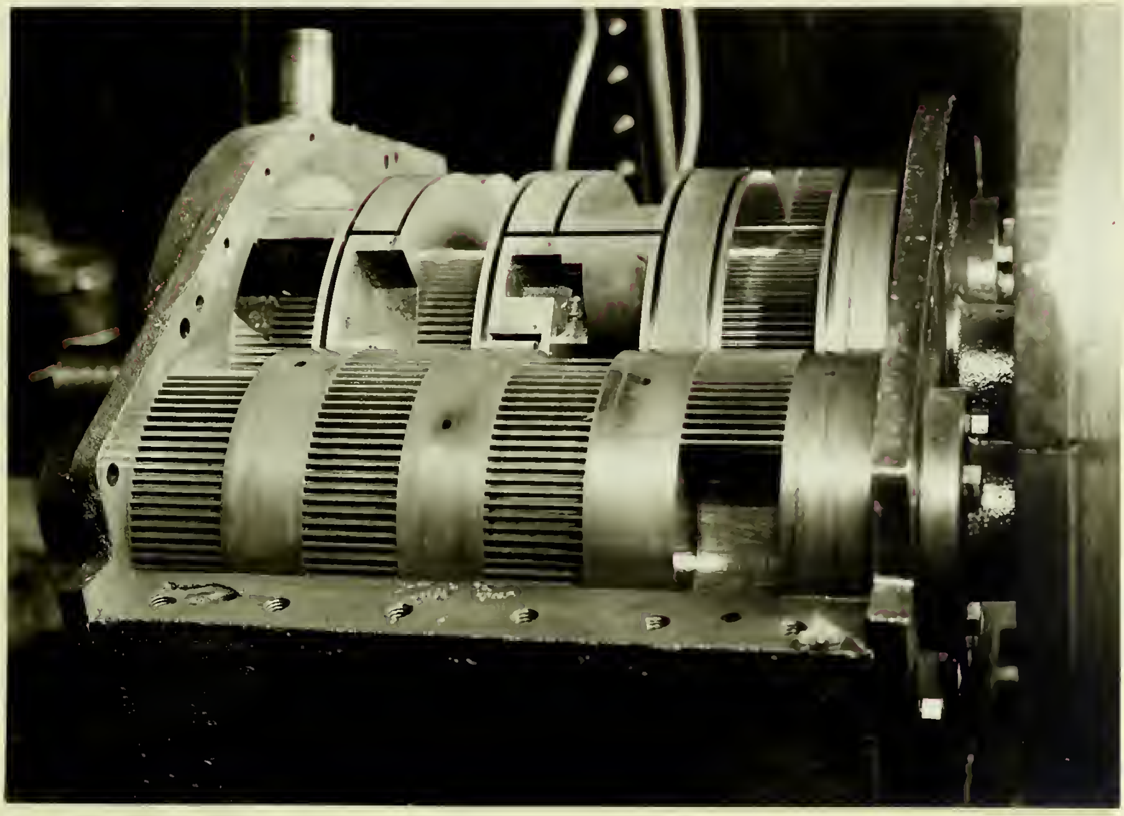
continuous gearing of both sets of rotary valves. The cycle relation with the primary expansion units fortunately is not disturbed. Likewise the two single unit expansion grooves in the center balance each other and maintain continuous meshing being 180° apart. The disk-valve action for the compounding can also be arranged conveniently. The ports from the primary expansion grooves are on their outside partitions, and the ports into the auxiliary groove are on the last wall. This utilizes every partition for valve action.

5. EXHAUST. In the paralleling arrangement of compound chambers it is evident that the exhaust from all must be simultaneous as the exhaust of one would destroy the pressure of all the others due to their interconnection. The exhaust port in the casing is tapped directly over the groove as near the rotary valve as possible. Then the expansion is effective until the lug's rear edge uncovers the exhaust port as it enters the valve cavity. During the next revolution all the burnt gases remaining are now forced out of the port ahead of the lug.

6. SIMULTANEOUS ACTIONS. As heretofore described, one charge passes thru the engine in three revolutions,but a new charge is taken in twice per revolution, therefore six operations are occuring simultaneously. In the first groove intake proceeds behind and compression ahead of the lug at the same time. In the second groove at that instant, primary expansion is in operation behind and exhaust ahead of its lug. In the third and fourth grooves compound expansion occurs behind and exhaust in front of their respective lugs.

PHOTOGRAPHS OF COMPLETED ENGINE.





CHAPTER VI.

PRACTICAL CONSIDERATIONS.

1. MECHANICAL FIT. As in all positive acting engines a mechanical fit is required. This necessitates good machine work and careful alignment. The fit need not be tighter than in an ordinary reciprocating engine. Equivalent piston rings and oil can be used in this rotary machine in nearly the same manner as in other engines. But unlike any piston and cylinder requirements, the rotary valve must fit both casing and rotor groove. Hence a slight axial motion of the rotor will tend to move the rotary valve also. Such motion of the valve is impossible, but the tendency would produce considerable wear.

Lubrication of the surfaces must be accomplished either by introducing oil with the gasoline or by some system of forced feed. The former is simple, but cannot be used if pressures and temperatures run very high, as the oil would burn with the gasoline. The latter system would be affected by centrifugal force, hence to lubricate the sides of the groove the oil must be introduced either at the bottom of the groove or from the sides of the rotary valve. If the oil is thrown toward the periphery of the valve it will be carried to the bottom of the groove, and all the surfaces oiled properly.

The rotor is rigidly supported in bearings, therefore the only casing wear is due to the piston rings which, however, from their position are constantly supplied with oil.

2. COMPRESSION. Production and maintenance of compression is dependent on motion and fit.

(a) Compression. Since the meshing of gear teeth in the bottom of the groove is depended upon to choke the escape of compressed gas, it is evident that a high speed of rotation will minimize the loss of compression in this manner. Furthermore, at the time the remaining compressed charge escapes ahead into the closed intake chamber, the rotary valve at the other end of this chamber has not yet reached its second critical point. Except for the line contacts with the other lug, the gas would circulate thru, and instead of compression there would be merely displacement. This is minimized also by a high rotational speed, hence it is evident that since rapid rotation causes so slight a loss of intake pressure it is advantageous to run at high speed.

(b) Maintenance. The disk-valve action as procured in this machine is scarcely tight enough to hold compression for a reasonable time. Accordingly the scheme of cumulative compression does not work out satisfactorily in practice. This can be remedied by using special valve mechanisms instead of employing the annular partitions. It is to noted, however, that the method described herein is the simplest arrangement, and further development may revert to this system.

3. OPERATION. For preliminary tests it will be found best to operate without compounding.

(a) Without Compound Unit. This can be accomplished by closing the 180° ports of the primary expansion chambers. Then the intake will equal the expansion and even with intermittent explosions there will always be a unidirectional motion of the gases thru the exhaust port.

For actual operation a standard carburetor is piped to the intake ports, water is circulated thru the cooling system to prevent warping and a continuous succession of sparks or a hot wire is used at the spark plug cavity. As the machine rotates the compression builds up and explosions occur. After minor adjustments have been made and the machine operates satisfactorily the exhaust will be at considerable temperature and pressure.

(b) With Complete Engine. Now the compound unit can be piped in to utilize this energy ordinarily thrown away at the exhaust, and the complete rotary internal combustion engine will be in full continuous operation, every chamber being filled with gas in some stage of the regular four-cycle reciprocating engine. Every space is continuously utilized and every part in true rotary motion, insuring high output rating with minimum outlay.

Frederick A. Brooks.

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